Future district heating systems
A need for dynamic, multi-physics simulation tools?

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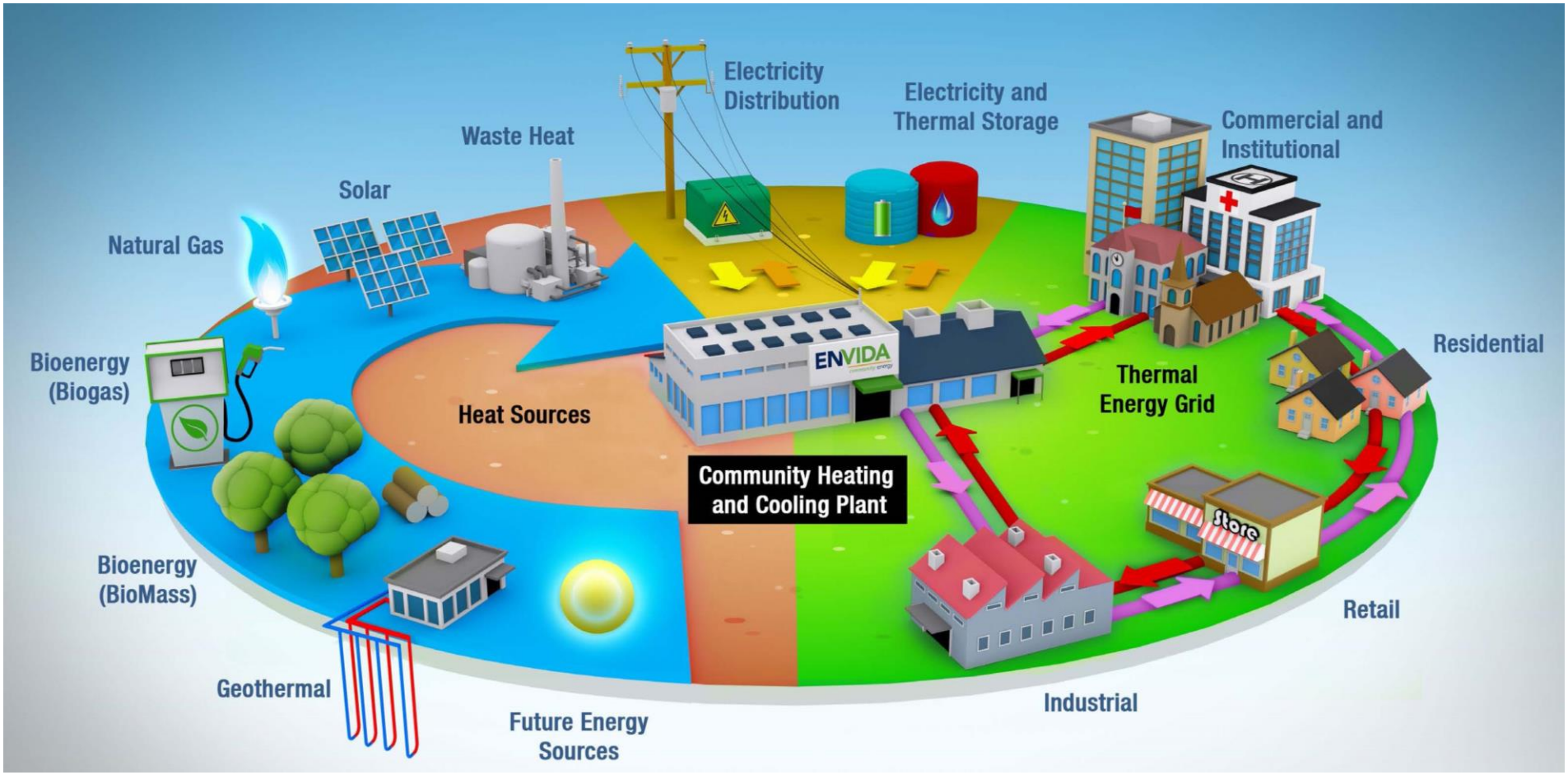
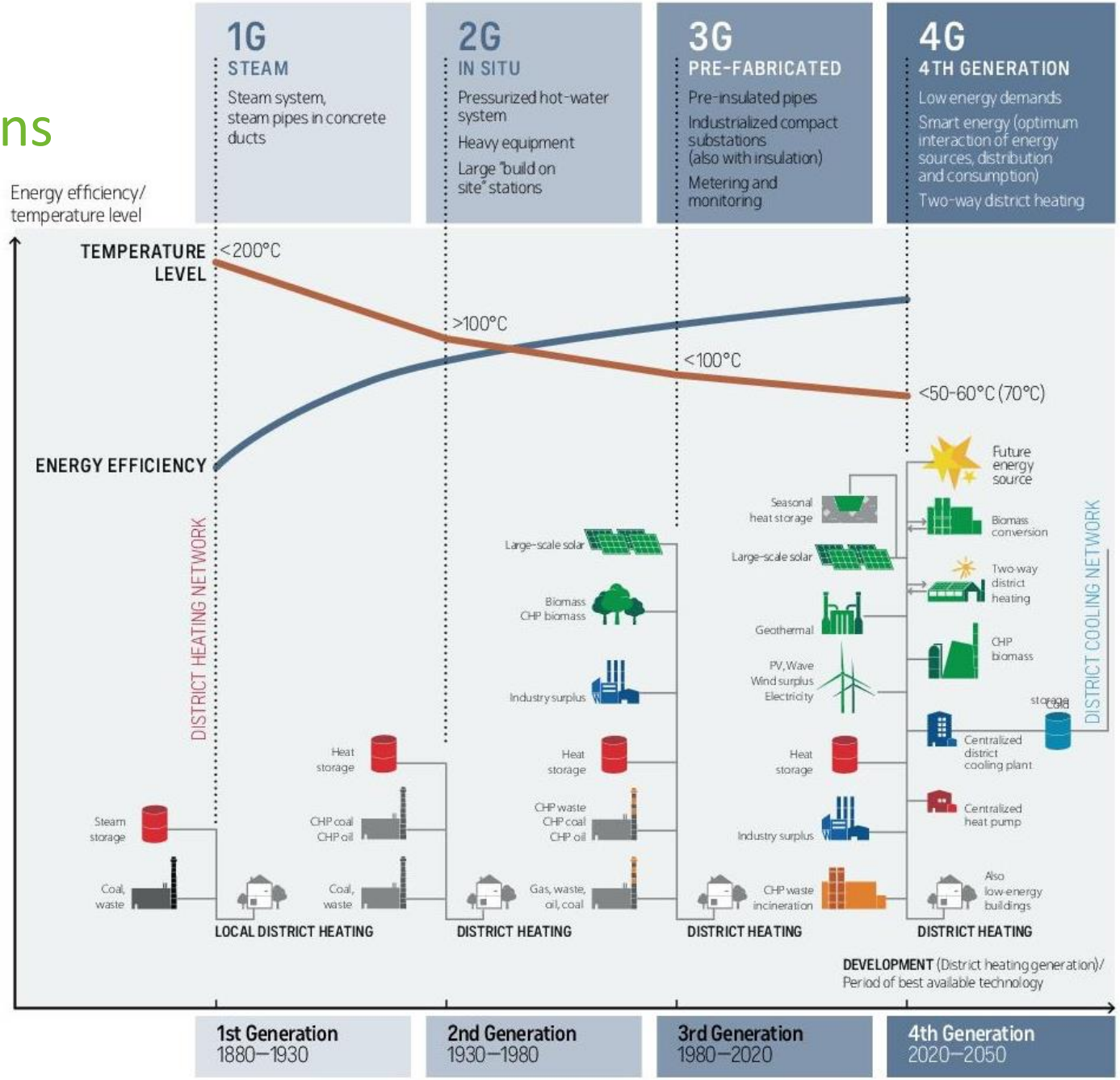
Context

District energy systems



Source: http://www.envida.ca/en/developingSustainableEnergy/resources/DISTRICT_ENERGY/Heat_Sources_for_Community_Energy_-_FINAL_-_A.jpg

TherNet generations



Lund, H *et al.* (2014). 4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems. Energy, 68, 1–11. article. https://doi.org/http://dx.doi.org/10.1016/j.energy.2014.02.089

Need for dynamic models

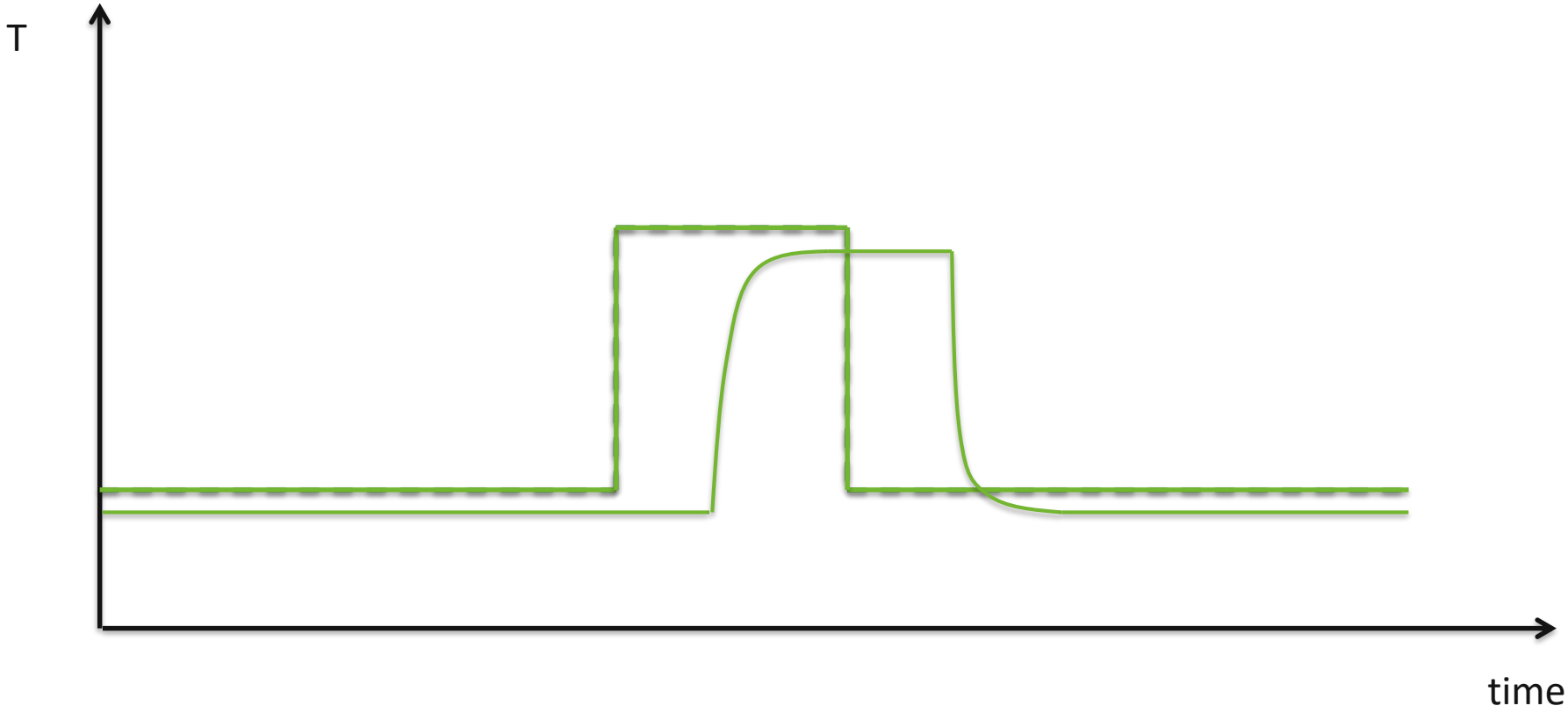
- Optimal design and operation
- Models need to be
  - Fast
  - Robust
  - Accurate

Novelties

- Novel open-source thermo-hydraulic model
- Application to a case study
- Comparison static and dynamic model

What we measure

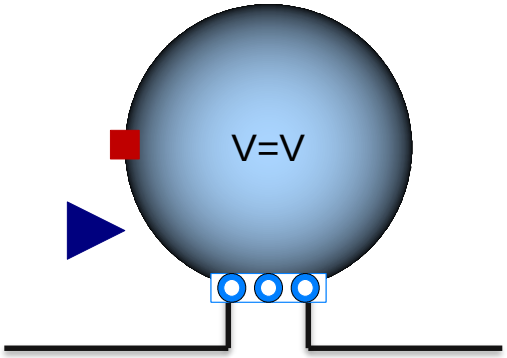
- Three processes:
  - Advection or propagation
  - Steady-state heat exchange
  - Transient effect



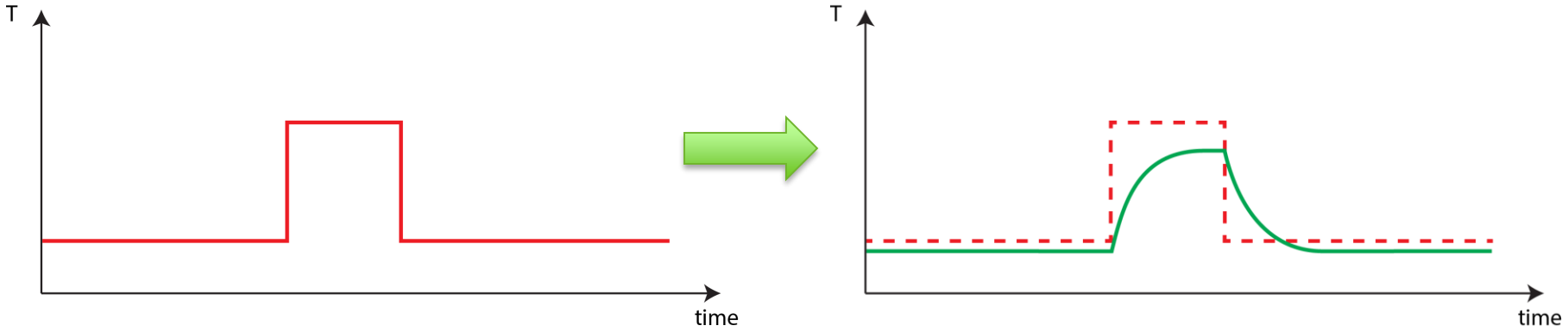
Single lumped capacity model

- Modelica: lumped mixing volume

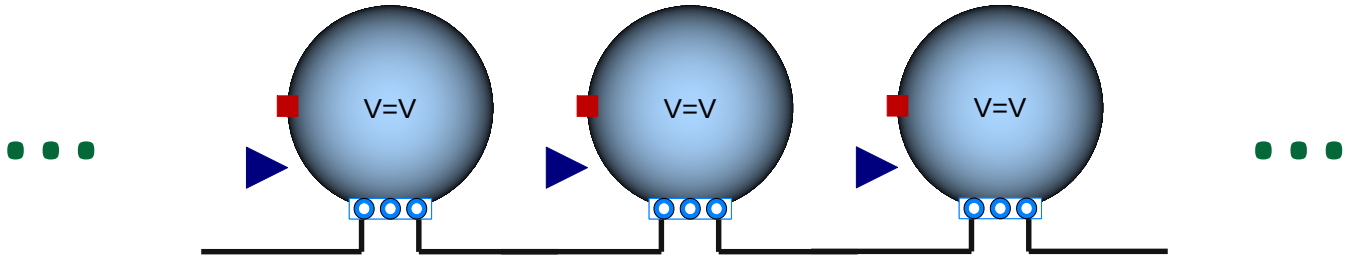
$$C\frac{\partial \bar{T}}{\partial t} = -\dot{Q}_e + \dot{m}(h_{in} - h_{out})$$



- Finite Δh ➔ immediate rise

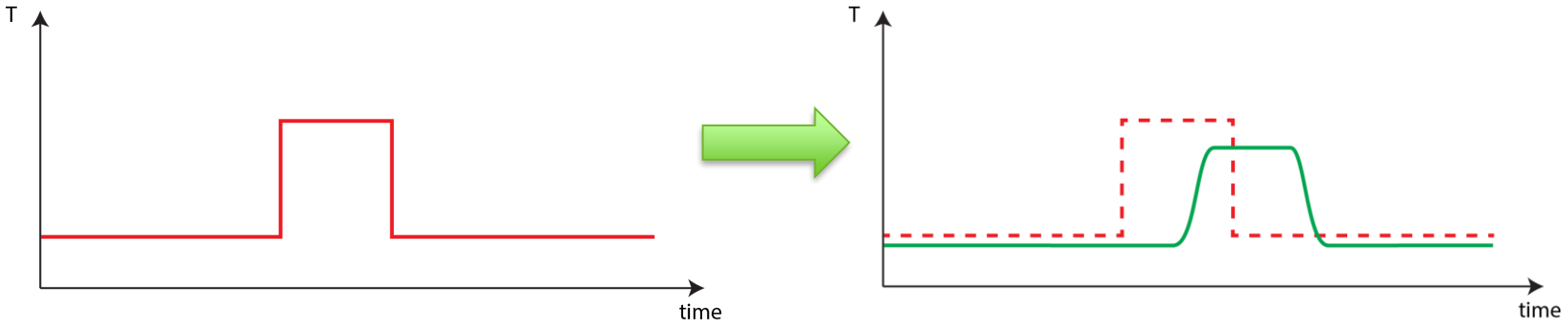


What we want <> What we get



- Modelica: multiple lumped mixing volumes

- Discretized pipe ➔ Numerical diffusion



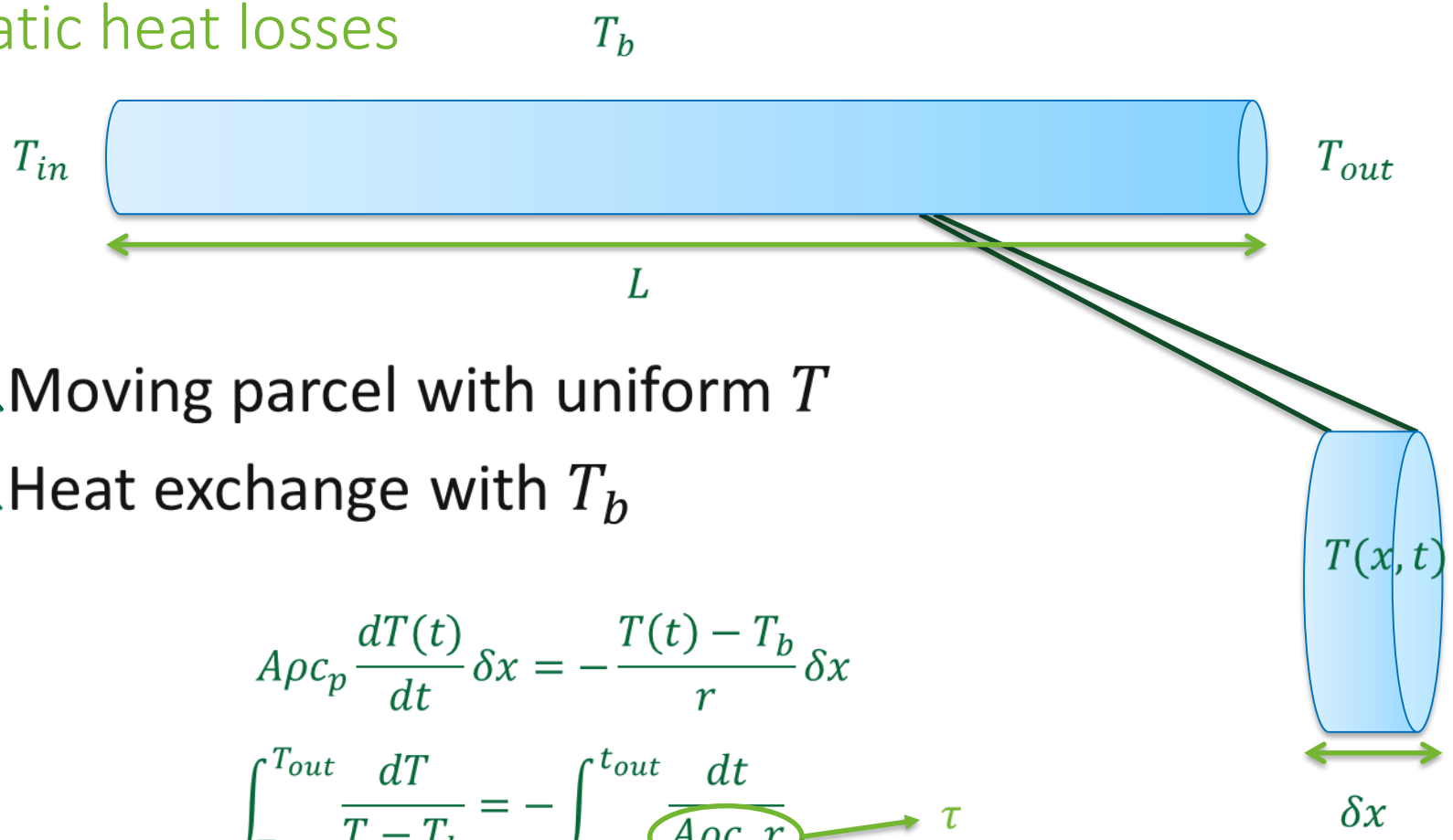
Node model

Overview

- Don’t split up pipe
- Split up heat transfer phenomena!
- Three processes:
  - Propagation → Delay block
  - Steady-state heat loss → Exponential decay
  - Dynamics → Lumped capacity

Node model

Static heat losses



- Moving parcel with uniform T
- Heat exchange with T_b

$$A\rho c_p \frac{dT(t)}{dt}\delta x = -\frac{T(t)-T_b}{r}\delta x$$

$$\int_{T_{in}}^{T_{out}} \frac{dT}{T-T_b} = -\int_{t_{in}}^{t_{out}} \frac{dt}{A\rho c_p r} \rightarrow \tau$$

$$T_{out} = T_b + (T_{in} - T_b)\exp\left(-\frac{\Delta t}{\tau}\right)$$

$r = R \cdot \delta x$:
thermal resistance
per unit length

Node model

Dynamics and hydraulics

- Dynamics
  - Lumped heat capacity at end of pipe
    - Only pipe wall material
  - Before heat losses are subtracted
- Hydraulics
  - Fixed hydraulic resistance
  - Turbulent regime
  - $\Delta P \sim \dot{m}^2$

Time delays and temperature propagation

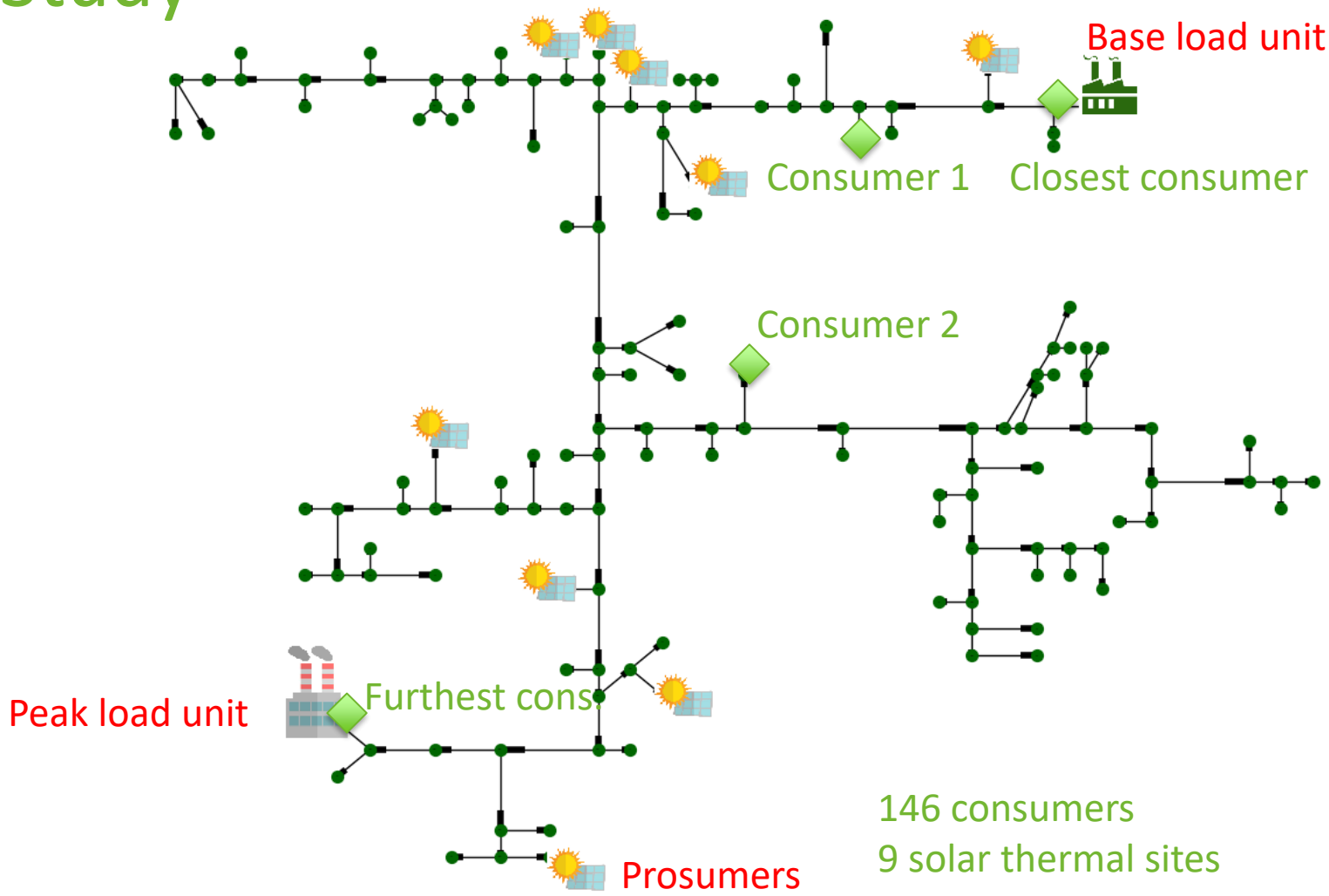
- Static approach:
  - Instantaneous calculation of time delay
  - $T_{out} = T_{in}(t) - \Delta T_{loss}(t)$
  - Less accurate, but requires less memory
- Dynamic approach:
  - Time delay: integral of previous mass flow rates
  - Actual propagation of temperatures
    - Using a shifting memory
  - $T_{out} = T_{in}(t - \Delta t) - \Delta T_{loss}(\Delta t)$
  - Most accurate

Model implementation

- Modelica
  - Part of IBPSA Project 1 Modelica Library
    - See https://github.com/ibpsa/modelica-ibpsa
    - Open Source
- Experimentally validated [1]

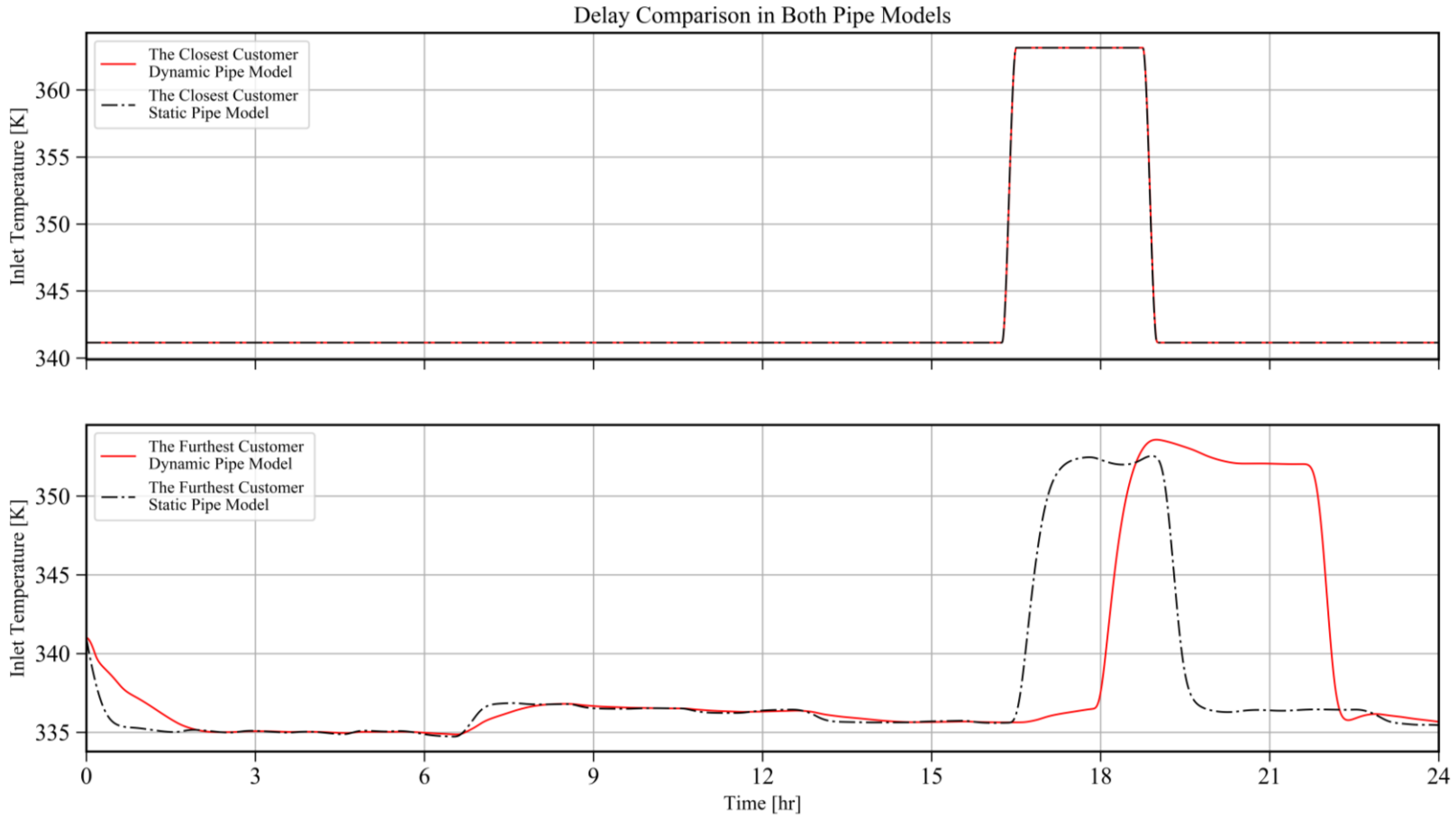
[1] van der Heijde, B *et al.* (2017). Dynamic equation-based thermo-hydraulic pipe model for district heating and cooling systems. *Energy Conversion and Management*, *151*(November), 158–169. https://doi.org/10.1016/j.enconman.2017.08.072

Case Study


Base load unit
Consumer 1
Closest consumer
Consumer 2
Peak load unit
Furthest cons
Prosumers
146 consumers
9 solar thermal sites

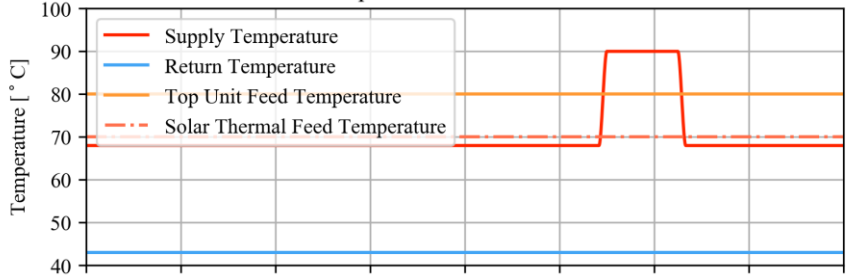
Results

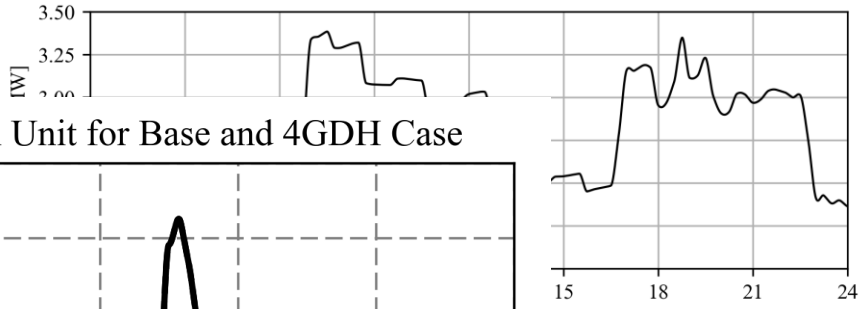
- Comparison Static ⇔ Dynamic, only Base Load Unit
  - 7.5 m ⇔ 2665 m

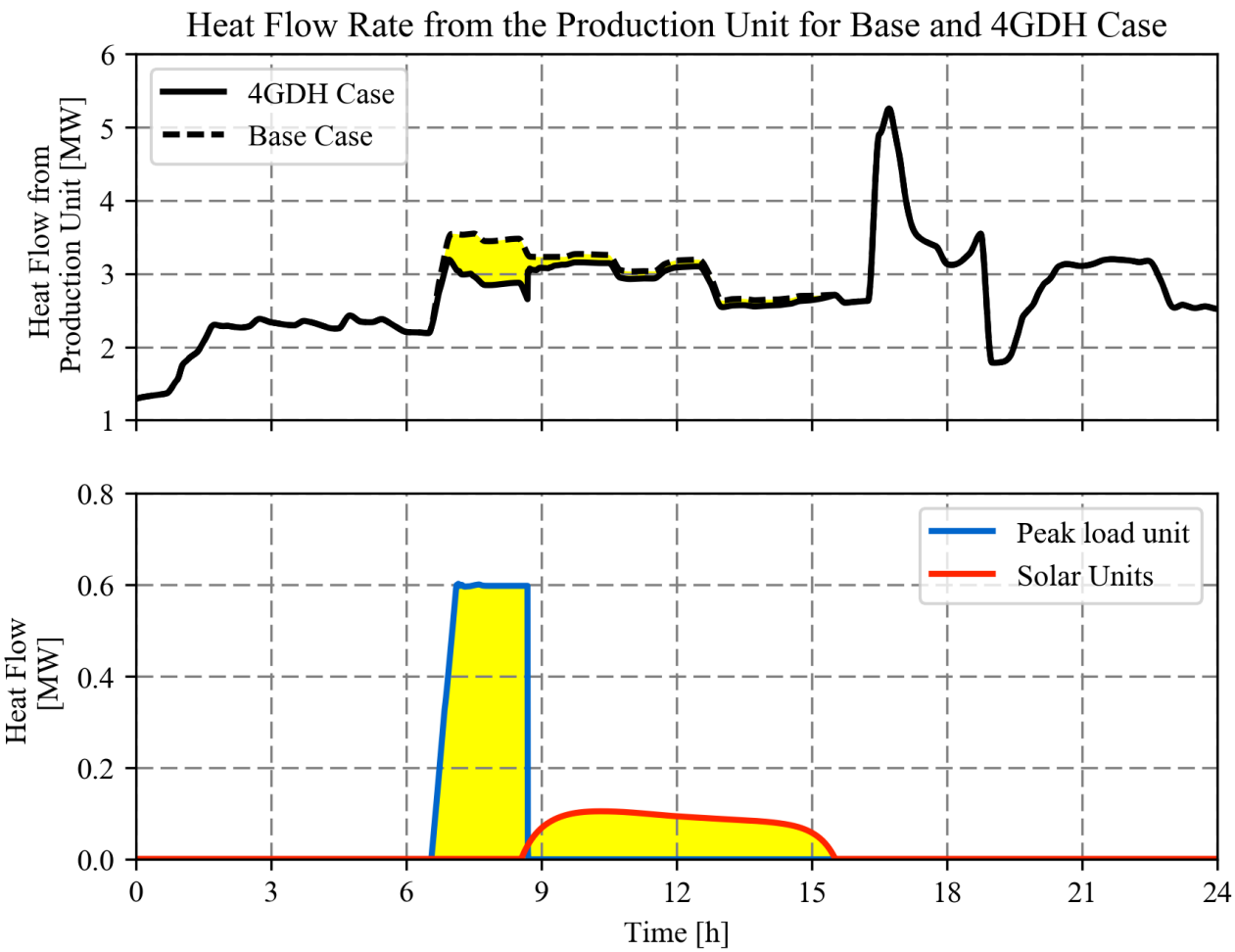


Results

- Comparison Base <=> 4DH







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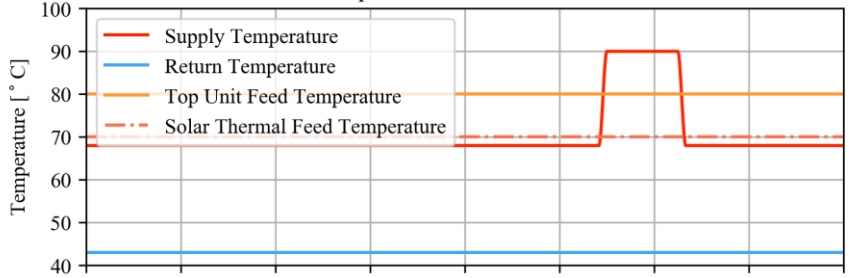

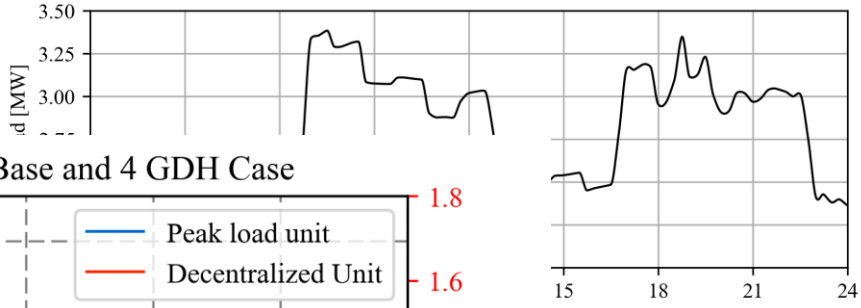

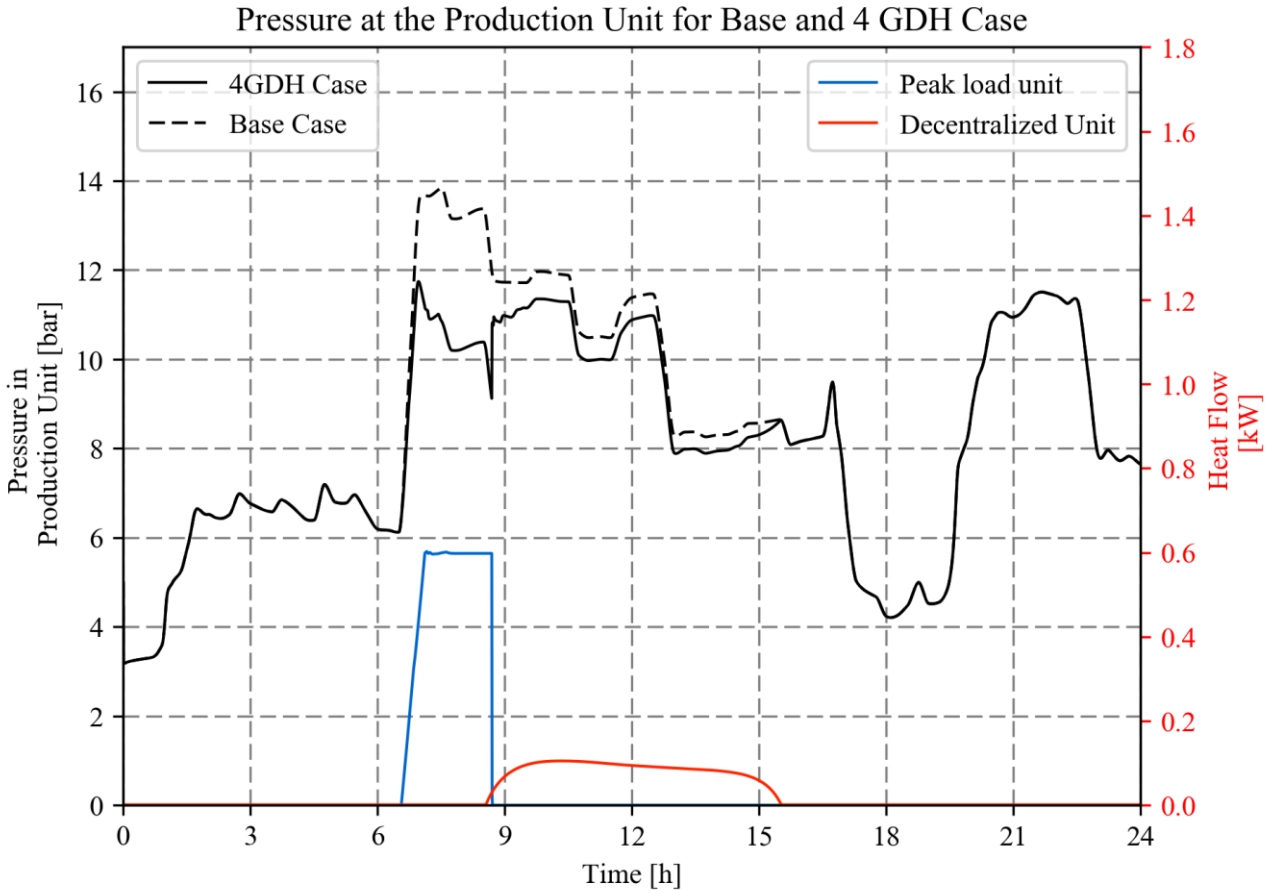

Open issues

- Non-linear systems due to minimal pressure difference controller
  - Slow simulations
- Linearization of pressure drops needed
  - Reduce non-linear systems
  - Increase simulation speed

Conclusion

- Thermal network simulations need dynamic models
- Trade-off between accuracy and speed
  - **Static** is 10x faster, but less accurate
  - **Dynamic** is very accurate
- Further improvements to speed up needed


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